

CHIMERIC PROTEINS FOR DIAGNOSIS AND TREATMENT OF DIABETESCROSS REFERENCE TO RELATED APPLICATION

This application claims priority from United States 5 provisional application serial No. 60/068,648, filed December 23, 1997, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The discussion in this section is not limited to subject matter that qualifies as "prior art" against the present 10 invention. Therefore, no admission of such prior art status shall be implied or inferred by reason of inclusion of particular subject matter in this discussion, and no declaration against the present inventors' interests shall be implied by reason of such inclusion.

15 Diabetes Mellitus

Diabetes mellitus is the most common endocrine disease, and is characterized by abnormalities of glucose metabolism. The abnormal glucose metabolism associated with this disease results in hyperglycemia (high blood glucose levels) and eventually 20 causes complications of multiple organ systems, including eyes, kidneys, nerves, and blood vessels. Patients with persistent hyperglycemia or abnormal glucose tolerance are generally diagnosed with the disease, although most commonly patients initially present with excessive urination (polyuria) and 25 frequent drinking due to extreme thirst (polydipsia). These typical initial symptoms result from the osmotic effects of hyperglycemia.

The pathogenesis of diabetes mellitus is typically associated with pancreatic dysfunction, particularly of the beta cells of 30 the pancreatic islets of Langerhans. This dysfunction may lead to destruction of the islet beta cells, which produce insulin, a glucose regulatory peptide hormone. Diabetes mellitus has been generally categorized as insulin dependent or type 1, versus non-insulin dependent, or type 2. However, this terminology has 35 evolved as the disease has become better understood. For example, it has been found that in some patients suffering from

non-insulin dependent diabetes, the disease progresses into an insulin dependent form, while in other patients insulin dependence does not develop.

Patients are thus often categorized in terms of the mechanisms of pathogenesis of islet destruction, and the designation type 1 is now used to refer to autoimmune islet pathogenesis, i.e., to diabetes caused by islet-specific autoimmune attack, and is so used herein. The term insulin dependent diabetes mellitus (IDDM) refers to Type 1 diabetes that has progressed to a stage where enough autoimmune destruction of the pancreatic beta cells has occurred to produce overt symptoms. The term pre-IDDM refers to an autoimmune condition that can be detected by biopsy or by analysis of autoimmune responses, in which pancreatic islet beta cells are being subject to a specific autoimmune attack to an extent where some cells may be subject to destruction. In pre-IDDM, however, the destruction (if any) has not progressed to an extent sufficient to require the administration of insulin. Since there can be a point in the early stages of Type 1 diabetes in which overt symptoms are observed but some islet function remains (known as the "honeymoon period"), not all Type 1 diabetes is classified as IDDM, and not all pre-IDDM presents without overt symptoms.

Complications of Type 1 Diabetes The metabolic complications associated with the abnormal metabolism caused by insulin insufficiency can affect numerous organ systems. The most common acute metabolic complication is that of diabetic ketoacidosis, characterized by severe hyperglycemia (and resulting hypovolemia caused by osmotic diuresis) as well as metabolic acidosis induced by excess free fatty acid release and the production of ketone bodies.

In addition to the acute metabolic complication of ketoacidosis, the diabetic patient is susceptible to a series of late complications that cause considerable morbidity and premature mortality. Atherosclerosis occurs more extensively and earlier in diabetics than in the general population as a

result of abnormalities in both glucose and lipid metabolism. This vascular pathology can lead to, *inter alia*, coronary artery disease, stroke, and peripheral vascular disease with gangrene. Retinopathy is another vascular complication of diabetes.

5 Diabetic retinopathy is a leading cause of blindness, and is initiated by increased permeability of retinal capillaries which can progress to occlusion, hemorrhage, aneurysm formation, and neovascularization known as proliferative retinopathy.

In addition to vascular complications, kidney and neurological 10 diseases (nephropathies and neuropathies) are common complications of diabetes. Diabetic nephropathy causes about half of end-stage renal disease in the United States. Histologically, the nephropathy is characterized by glomerular basement membrane widening and mesangial thickening. Initial 15 signs include increasing proteinuria, with azotemia ultimately leading to renal failure. Diabetic neuropathy can affect any part of the nervous system, with the possible exception of the brain. The neuropathy is most commonly seen as peripheral polyneuropathy, with symptoms including numbness, paresthesias, 20 severe hyperesthesia, and pain. Autonomic neuropathy can cause gastrointestinal dysfunction, orthostatic hypotension, bladder dysfunction or paralysis, and impotence. Diabetic foot ulcers represent a special problem of diabetics, and appear to be due primarily to abnormal pressure distribution secondary to 25 diabetic neuropathy. The ulcerous lesions are often worsened by concomitant peripheral vascular disease and infection.

As mentioned above, meticulous control of blood glucose has been associated with amelioration of the late complications of Type 1 diabetes, suggesting that that preservation or 30 restoration of beta cell function could reduce or eliminate the majority of the pathologic complications of the disease.

Pathogenesis of Type 1 Diabetes Type 1 diabetes only develops in genetically susceptible individuals, and symptoms generally appear before age 40, with the peak incidence of onset of overt 35 symptomatology occurring in the second decade of life. The

pathogenesis of Type 1 diabetes is characterized by an initial phase of leukocyte infiltration into the islets, referred to as insulitis, followed over a period of time by the actual destruction of the islet beta cells by autoimmune attack. The 5 insulitis phase is characterized by infiltration of pancreatic islets by both lymphocytes and cells of the monocyte/macrophage lineage, and entails both cell-mediated inflammation as well as attack by islet-specific cytotoxic antibodies. Overt clinical symptoms of diabetes mellitus are generally manifested when over 10 90% of the islet beta cells are destroyed; however, as discussed more fully below, it is now possible to accurately detect individuals undergoing earlier stages of type 1 pathogenesis, i.e., before enough islet beta cells have been lost to produce overt clinical symptoms.

15 The autoimmune process is generally thought to be induced by an environmental stimulus. One reason for this belief is that an identical twin has only a fifty / fifty chance of developing IDDM if his identical sibling has the disease.

T Cells The autoimmune destruction of the beta cells of the 20 pancreatic islets in Type 1 diabetes is believed to be initiated by white blood cells (leukocytes), most importantly T cells. T cells, or T-lymphocytes, are mononuclear white blood cells that provide many essential immune functions. The importance of T cells in human autoimmune diseases has been increasingly 25 appreciated in the past two decades. Studies using treatments that result in generalized immunosuppression have defined a critical role for a subset of T cells, known as CD4⁺ or helper T cells, as primary regulators of all immune responses (both cellular and humoral) to protein or peptide antigens.

30 T cells mediate tissue injury by indirect and direct means. T cells of both CD8⁺ (cytotoxic) and CD4⁺ (helper) subsets secrete a variety of inflammatory cytokines that can damage tissues indirectly by activating various other types of white blood cells. Examples of such T cell effects include activation of

antibody secreting B cells (stimulating humoral immune activity) and activation of macrophages, which can cause acute tissue damage and inflammation by releasing hydrolytic enzymes, reactive oxygen species, and additional pro-inflammatory 5 cytokines. In addition to these indirect effects of T cell activity, direct tissue damage can be mediated by CD8⁺ cytotoxic T cells attacking cells displaying target antigens.

One unique aspect of the physiology of T cells is the presence of membrane bound antibody-like binding structures called T cell 10 receptors (TCRs) on their cell surfaces. Like antibodies, TCRs bind with high specificity to particular antigens. Like antibody-producing cells, which develop as multitudinous clones of cells, each clone producing antibodies with unique 15 specificities, T cells develop as a vast number of distinct clones, and any particular T cell clone expresses a single type of TCR with a defined binding specificity. T cell clones with TCRs that bind specifically to self antigens are responsible for the development of autoimmune diseases.

Studies of the interactions of antibodies and TCRs with their 20 specific antigens have shown that a particular polypeptide antigen typically comprises numerous submolecular features, known as epitopes, that each can serve as a distinct binding site for a particular antibody or TCR.

T Cells and Autoimmune Diseases In autoimmune diseases, only a 25 limited number of T cell clones, reactive with various epitopes of a small number of autoantigens, become activated and are involved in pathogenesis. Even in individuals suffering from autoimmune diseases, only a small percentage of T cell clones (0.1-1%) are known to recognize autoantigens.

30 Various mechanisms have been postulated to play a role in the pathogenic activation of disease-causing autoreactive T cells. Primary activation of antigen presenting cells (APCs) by infection or local inflammation is implicated in one such mechanism. APCs activated in this way can then provide powerful 35 co-stimulation for hitherto unreactive T cells.

Other proposed mechanisms involve the polyclonal activation of previously quiescent autoreactive T cells by superantigens, such as bacterial toxins; or a coincidental molecular mimicry between foreign and self antigens (Abbas et. al. 1994). In this last 5 case, the host immune system mounts a response to an epitope on a protein expressed by a pathogen, such as a virus, that resembles a homologous epitope on a host protein. Autoimmune attack then results from the cross-reactive immune response that ensues.

10 In addition to external factors, underlying the emergence of all T cell-mediated autoimmune disease is a complex pattern of inherited susceptibility determined by multigenic factors. For further discussions of these various factors, Steinman, 1995, reviews current theories of autoimmunity.

15 Alterations in the T cell repertoire occur naturally during T cell development. Only a small fraction of thymocytes (immature T cells) survive the intrathymic development and selection events that result in emigration of developing T cells to the peripheral circulation and the completion of their maturation 20 (von Boehmer, 1988; Marrack and Kappler, 1987). Experimental evidence strongly suggests that a large number of thymocytes that bear receptors for autoantigens are initially present in the thymus. Recent studies have yielded evidence suggesting that a process referred to as programmed cell death, or 25 apoptosis, destroys these autoreactive thymocytes in the thymus while sparing thymocytes that are not autoreactive. Apoptosis thus plays a large role in shaping and maintaining the T cell repertoire and contributes to the establishment of self-tolerance by actively eliminating cells expressing autoreactive 30 TCRs.

It has recently been discovered that T cells are sensitive to apoptotic cell death induced by a variety of stimuli at multiple points in their lifespan (see, for example, Lenardo 1991; Boehme and Lenardo 1993; Critchfield et al. 1994). Positive selection 35 factors are also believed to play a role in regulating the

survival of specific T cell clones. The reduction or expansion of the number of individual T cells of a particular clone in an organism by these and other mechanisms serve to modulate the responsiveness of the organism's immune system to a particular 5 antigen. It is now firmly established in several autoimmune disease models, as well as in certain viral infections, that apoptosis can be induced (upon exposure to antigen under certain defined conditions) in mature peripheral antigen-specific T lymphocytes as well as in immature thymocytes.

10 Apoptosis occurs in many biological systems (see, for example, Kerr et al. 1991; Lockshin and Zakeri, 1991; Cohen et al. 1992; Duvall and Wyllie, 1986; Cotter et al. 1990). A cell undergoing apoptosis undergoes a specific program of events -- cellular and biochemical processes that depend upon active metabolism and 15 contribute to the cell's self-destruction. In apoptotic T cells, the nucleus shrinks, the chromatin condenses, the genetic material (DNA) progressively degrades into small (nucleosomal repeat sized) fragments, there is cytoplasmic compaction, the cell membrane forms blebs, and the cell eventually collapses 20 (Kawabe and Ochi, 1991; Smith et al. 1989). Cells cannot recover from apoptosis, it results in irreversible cell death (Kawabe and Ochi, 1991; Smith et al. 1989).

Recent reports have suggested a role for the TNF-related cytokine known as the FAS ligand and its receptor, CD95 (the FAS 25 receptor), in the induction of apoptosis in T cells (Crispe et al. 1994; Nagata and Suda, 1995; Strasser, 1995; Dhein et al., 1995; Brunner et al., 1995; and Ju et al., 1995).

Islet Beta Cell Autoantigens As discussed above, the onset of Type 1 diabetes is considered to be mediated by T cells. The 30 disease is believed to be a consequence of inappropriate T cell responses specific to certain islet beta cell proteins that act as autoantigens. In addition to autoreactive T cells, autoantibodies against various self antigens have also been reported in IDDM patients. The antigens reported to be bound by 35 these autoantibodies include many of those that have been

reported to be recognized by autoreactive T cells.

Autoantigens that are subject to autoimmune responses in Type 1 patients include the 64-65kDa GAD (glutamate decarboxylase) and the 67kDa GAD autoantigens; insulin; sialyglycolipid; a 38kD

5 antigen from the secretory granules of beta cells; an antigen cross reactive with antibodies to bovine albumin known as the beta cell p69 protein, PM-1, or disease-modifying antigen, a beta cell cytoskeletal protein known as peripherin, glucose transporter proteins, including GLUT-2; heat shock protein 65

10 (HSP 65), including the p277 peptide; carboxypeptidase H; a 52kD molecular mimic of Rubella virus antigen; a beta cell membrane associated protein of 150kDa; a protein antigen located at the secretory pole of the rat insulinoma cell line RINm38, referred

15 to as the RIN polar antigen; and (at first) poorly characterized antigens isolated by immunoscreening of an islet cDNA expression library, referred to as ICA12 and ICA512. ICA512, now also known as IA-2, is immunologically related to phogrin, which is also subject to autoimmune responses in Type 1 patients (Hatfield et al., 1997).

20 The relative importance of these various autoantigens to autoimmune pathogenesis, and the timing with which each plays a role during the course of disease onset and development, are the subject of considerable uncertainty and consequent controversy in the art. Further uncertainty stems from the fact that each

25 supposed autoantigen comprises numerous epitopes, some of which may be have disease promoting effects while others may have disease suppressive effects.

While not wishing to be bound by any particular theory of operation, in accordance with certain aspects of the invention

30 insulin and GAD are believed to provide the most effective therapeutic effects on the development of Type 1 diabetes of any of the autoantigens implicated as playing a role in the pathogenesis of the disease. In accordance with certain other

35 aspects of the invention, IA-2 is also believed to provide effective therapeutic effects.

Autoantibodies to 64-65kD GAD (hereinafter GAD 65) normally are detected before the onset of clinical insulin dependent Type 1 diabetes mellitus, and among nondiabetic relatives of patients with IDDM as well as others at risk. These autoantibodies have 5 been suggested to be the best predictive autoantibody marker for impending Type 1 diabetes.

GAD 65 and GAD 67 are encoded by different genes on different chromosomes, the genes being about 70% homologous. Human islets only express GAD 65, although both protein forms are found in 10 the brain. Evidence of lymphocyte specific immunity to GAD 65 has been demonstrated and found to be closely associated with IDDM. Recent studies in the NOD mouse model of diabetes have indicated that T cell responses to GAD 65 precede those to other putative autoantigens and that early induction of T cell 15 tolerance to GAD 65 can prevent onset of disease.

Kaufman et al (1993) and Tisch et al (1993) have presented data that suggest that GAD responses are the most important in disease development, as they were reported to arise first during the development of Type 1 diabetes, with responses to other beta 20 cell autoantigens only appearing much later in the course of the disease, with insulin reactivity being amongst the last to appear. These findings were interpreted as indicating that GAD 65 is the key autoantigen in Type 1 diabetes, and that modulation of autoimmune reactivity with GAD would be the most 25 appropriate target for reducing disease pathology. In accordance with this theoretical understanding of disease progression, modulation of insulin reactive T cells would be closing the barn door after the horses had gone, the anti-insulin reactions being observed so late in disease progression 30 that their modulation would not be expected to affect the onset or severity of disease.

Insulin autoantibodies (IAA) can be detected in around 50% of new onset patients, and are highly associated with islet cell autoantibodies (ICA) and the HLA-DR4 phenotype. Other studies 35 suggest that individuals with both ICA and IAA have a much

higher risk for developing overt Type 1 diabetes than those with either marker alone. T cell responses to insulin as an autoantigen have also been described. In one study cellular responses to human insulin were present in almost 90% of ICA-
5 positive first degree relatives of IDDM patients. Also, as discussed below in the examples, insulin reactive T cells from diabetic NOD mice can transfer diabetes to non-diabetic NOD mice.

Responses of T cells from Type 1 diabetes patients or from at-risk individuals to undefined islet cell preparations have suggested that T cells also respond to other islet cell antigens. These include a 38kD antigen from the secretory granules of beta cells, and serum albumin. In addition, heat shock protein (HSP) 65 has been implicated as a T cell autoantigen based upon the finding that HSP-specific T cells transfer disease in NOD mice.

Carboxypeptidase H is a molecule found in islet secretory granules and is associated with the production of peptide hormones and neurotransmitters. It was identified as a potential islet autoantigen by the screening of cDNA expression libraries with sera from IDDM or pre-IDDM patients.

Several other putative islet cell antigens, such as ICA12 and ICA512, have also been identified by screening of cDNA expression libraries.

Intra-antigenic and inter-antigenic spread of autoreactivity ("epitope spreading") are related phenomena associated with autoimmune diseases in which additional epitopes within an antigen, or additional antigens within a target tissue, become targeted by autoreactive T cells during disease progression. Such antigen spreading has been observed during the course of the inflammatory autoimmune process in the murine models of experimental allergic encephalomyelitis (EAE) and insulin-dependent diabetes (Lehmann et al. 1992; McCarron et al. 1990; Kaufman et al. 1993; Tisch et al. 1993).

These findings of antigen/epitope spreading suggest that for a therapeutic treatment to provide effective immune tolerance to islet beta cell autoantigens, the treatment will need to target a heterogeneous population of specific autoreactive T cells.

5 Therefore, in order for antigen administration to be maximally effective in the prevention and treatment of Type 1 diabetes, it is desirable that a plurality of the immunodominant epitopes of both insulin and GAD 65 be presented to the disease producing autoreactive T lymphocytes.

10 Prediction and Diagnosis of Type 1 Disease As discussed above, there is a genetic aspect to the incidence of Type 1 diabetes. Accordingly, genetic tests can identify certain individuals at increased risk of developing the disease (see, for example, Walston et al. 1995). Furthermore, individuals with a known 15 family history of the disease can be monitored for early, preclinical signs of disease development, e.g., by monitoring levels of the autoantibodies and autoreactive T cells discussed herein.

Autoantibodies Among the autoantibodies known to be associated 20 with Type 1 diabetes, those directed against GAD 65 are the ones that appear earliest and are present in the largest number of patients. Overall, recent studies have shown that over 80% of individuals with preclinical diabetes have GAD-specific autoantibodies. In this case an individual with preclinical 25 disease is defined as a first degree relative of a Type 1 diabetes patient with ICA. The antigens identified by ICA are ill-defined, but together with IAA and GAD-specific autoantibodies, they yield a high predictive value for onset of diabetes in preclinical individuals. Interestingly, in actual 30 early onset disease, the frequency of GAD-specific antibodies declines. This could be due to the fact that GAD 65 reactivity declines with beta cell destruction.

Prediction of Type 1 diabetes may also be facilitated by monitoring of the subject's blood sugar levels, preferably, in 35 conjunction with the administration of a glucose tolerance test

to the subject. Such procedures are preferably carried out in combination with the monitoring of titers of the subject's circulating IAA, ICA, and GAD autoantibodies.

In accordance with the present invention, the chimeric 5 proteins of the invention are fusion proteins that may be used as antigenic substrates for the detection of circulating autoantibodies, particularly IAA and/or GAD 65 autoantibodies, in diagnostic assays such as Western blot, ELISA, RIA, ELISPOT, and the like.

10 T cells Assays for the detection of T cells with specific reactivities are well known in the art, and include the mixed lymphocyte reaction (MLR) and the ELISPOT assay. ELISPOT assays are described, for example in Taguchi et al., J Immunol Meth 1990, 128:65 and Sun et al., J Immunol 1991 146:1490. In 15 accordance with the invention, the chimeric fusion proteins of the invention may be used as substrates in such assays for the detection and quantification of insulin reactive T cells and/or GAD 65 reactive T cells and/or IA-2 reactive T cells.

Current Methods for Prevention and Treatment of Type 1

20 Diabetes. While diabetes has been studied for centuries, only a few effective treatments are available for type 1 disease. The first line of treatment is diet, with appropriate caloric intake based on ideal body weight and a defined distribution among protein, glucose, and fat. However, in IDDM patients, the most 25 important component of therapy is the administration of insulin, the goal of which is to maintain glucose levels as close to the normal range as possible throughout the day. Insulin is available in rapid, intermediate, and long-acting formulations which vary in onset, peak, and duration of action, and can be 30 used in varying schedules of administration to attempt to optimally regulate plasma glucose levels.

Intensive insulin therapy refers to a rigorous regimen of administration of hormonally effective insulin and monitoring of blood sugar levels. This regimen is designed to control blood 35 glucose as precisely as possible. The results of the

multicenter Diabetes Control and Complication Trial established that complications of diabetes are significantly diminished by better control of blood glucose levels, and thus demonstrated the desirability of intensive insulin therapy. One problem with 5 this approach is that intensive insulin therapy requires a high level of patient awareness and compliance, as well as a highly skilled care team of physicians, nurses, and dietitians. The goals of intensive insulin therapy are thus extremely difficult to achieve, even with motivated and educated patients. Another 10 problem is that a higher rate of hypoglycemia is seen in such rigorously treated patients than in patients receiving standard, less rigorous, insulin regimens.

The Diabetes Control and Complication Trial highlighted not only the benefit to overall metabolic health of maintaining 15 normal blood glucose levels, but also a fundamental problem associated with the treatment of Type 1 diabetes, namely that the overt symptoms of the disease are manifested only when essentially all of the patients' islets are destroyed. Oral agents for diabetes, such as the sulfonylureas, act primarily by 20 stimulating the release of insulin from dysfunctional beta cells, and thus are not useful for most patients with type 1 disease, i.e. for those patients with IDDM.

A major goal in the treatment of diabetes has been to develop therapies capable of aborting the autoimmune attack on the islet 25 beta cells prior to their complete destruction, thereby preserving enough endogenous function to maintain normal metabolic control.

Induction of tolerance In the NOD (non-obese diabetic) mouse model of diabetes, it has been shown that oral feeding of 30 insulin delayed the onset and reduced the severity of the disease. The mechanism proposed to explain oral tolerance is that oral antigen administration induces populations of antigen-specific Th2 T cells that secrete antiinflammatory cytokines such as IL-4, IL-10, and TGF-beta. These T cells circulate and 35 are activated to secrete cytokines only in the presence of their

specific antigen. Thus, insulin-specific Th2 T cells would be activated only in the pancreas where they would produce suppressive cytokines to modulate the autoimmune process. This mechanism does not require, therefore, that the oral antigen 5 actually represent a disease-specific autoantigen, but rather only that it is expressed in a tissue specific fashion.

In contrast, methods designed to produce T cell tolerance (e.g., by anergy or apoptosis) require the identification of the actual disease-specific autoantigens that are targeted by 10 autoimmune attack. Such antigens are then administered to patients in an appropriate tolerizing fashion (which may also induce non-antigen-specific tolerizing effects). Given that Type 1 diabetes is in significant measure a disease mediated by islet-specific autoreactive T cells, therapy of this type should 15 be feasible in principle. Thus, induction of neonatal tolerance to GAD 65, as referred to above, prevented onset of disease in NOD mice. In addition, injection of crude islet extracts intrathymically, where tolerization of developing T cells takes place, has also protected both NOD mice as well as pre-diabetic 20 BB rats from developing clinical disease.

One approach taken to induce insulin tolerance involves the parenteral administration of insulin, in combination with a conventional adjuvant (e.g., Freund's adjuvant). Typically this approach involves the administration of doses of insulin that 25 would not be large enough to be expected to cause insulin shock in the patient. Notably, the insulin moieties of the chimeric fusion proteins of the present invention are hormonally ineffective, and are thus suitable for use in accordance with the methods of U.S. application No. 08/565,769, filed in the 30 name of Yi Wang, which is incorporated herein by reference.

Apoptosis Apoptosis is a form of programmed cell death that occurs in many biological systems (Kerr et al., 1991; Lockshin and Zakeri, 1991; Cohen et al., 1992; Duvall and Wyllie, 1986; Cotter et al., 1990). As discussed above, an apoptotic cell 35 undergoes a specific program of events that depend upon active

metabolism and contribute to its own self-destruction. T cells that do not undergo apoptosis, but which have become activated, will carry out their "effector" functions by causing cytolysis, or by secreting lymphokines that cause B cell responses or other 5 immune effects (Paul, 1989, pp. 3-38). These "effector" functions are the cause of tissue damage in autoimmune and other diseases. A powerful approach to avoiding disease is thus to permanently eliminate by apoptosis only those T cells reactive with autoimmune disease-inciting antigens, while leaving the 10 majority of the T cell repertoire intact. The use of auto-antigens to carry out this approach is described in PCT patent publication No. 94/28926, filed in the name of Michael J. Lenardo, and entitled Interleukin-2 Stimulated T Lymphocyte Cell Death for the Treatment of Autoimmune Diseases, Allergic 15 Disorders, and Graft Rejection, and PCT patent publication No. 94/03202, filed in the name of Michael J. Lenardo, Stefen A. Boehme, and Jeffrey Critchfield and entitled Interleukin-4 Stimulated T Lymphocyte Cell Death, both of which patent publications are incorporated herein by reference.

20 Transplantation Transplantation of healthy pancreata, pancreatic tissue, or isolated pancreatic islets into patients suffering from Type 1 diabetes provides an effective treatment modality. Unfortunately, the duration of the therapeutic benefit of such transplants is currently limited by the same 25 autoimmune phenomena that cause type 1 disease in the first place. Accordingly, treatment of a diabetic patient using the chimeric fusion proteins of the invention in accordance with the methods of the present invention, when carried out prior to, concomitantly with, and/or shortly after such a transplant, will 30 increase the longevity of such transplants and thereby enhance the therapeutic benefit of such transplantation procedures.

The accompanying figures, which are incorporated in and constitute part of the specification, illustrate certain aspects of the invention, and together with the description, serve to 35 explain the principles of the invention. It is to be

understood, of course, that both the figures and the description are explanatory only and are not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a shows a schematic diagram of the IG1 fusion protein (SEQ ID NO:1). The numbers following the backslashes in the legend indicate the GAD 65 peptide moiety to which region corresponds. For hGAD 65/473-5--, 5-- indicates 555.

Figure 1b shows a schematic diagram of the IG2 fusion protein (SEQ ID NO:2). The numbers following the backslashes in the legend indicate the GAD 65 peptide moiety to which region corresponds. For hGAD 65/473-5--, 5-- indicates 555.

Figure 1c shows a schematic diagram of the IG3 fusion protein (SEQ ID NO:3). The numbers following the backslashes in the legend indicate the GAD 65 peptide moiety to which region corresponds. For hGAD 65/473-5--, 5-- indicates 519.

Figure 2 shows the results of CYTOXAN induced IDDM experiments in which NOD mice were treated with bovine serum albumin (BSA, as control) insulin chain B (ICB) human GAD 65 peptide 250-273, or human GAD 65 peptide 520-555 (a peptide with a sequence corresponding to amino acid residues 139-173 of SEQ ID NO:2).

Figure 3 shows the results of CYTOXAN induced IDDM experiments in which NOD mice were treated with bovine serum albumin (BSA, as control) or the following mixtures of insulin chain B (ICB) and human GAD 65 peptides : 1) 100 µg each of ICB and human GAD 25 65 peptide 250-273, 2) 250 µg each of ICB and human GAD 65 peptide 250-273, 3) 100 µg each of ICB, human GAD 65 peptide 250-273, and human GAD 65 peptide 520-555, and 4) 250 µg each of ICB, human GAD 65 peptide 250-273, and human GAD 65 peptide 520-555.

30 Figure 4 shows the results of CYTOXAN induced IDDM experiments in which NOD mice were treated with bovine serum albumin (BSA, as control) or 100 µg of the IG1 chimeric protein, 250 µg of the IG1 chimeric protein, 100 µg of the IG2 chimeric protein, or 250 µg of the IG2 chimeric protein.

Figure 5 shows the results of the adoptive transfer of IDDM experiments.

Figure 6 shows a schematic diagram of the IG4 fusion protein (SEQ ID NO:4). The numbers following the backslashes in the legend indicate the position of the indicated peptide moiety component in native human GAD 65 from which its sequence was derived, while the aa numbers in parentheses the corresponding amino acid numbers in SEQ ID NO:4, and the notation GGG indicates the incorporation at that point of a three glycine helix-breaking linker.

Figure 7 shows a schematic diagram of the IG5 fusion protein (SEQ ID NO:5). The numbers following the backslashes in the legend indicate the position of the indicated peptide moiety component in native human GAD 65 from which its sequence was derived, while the aa numbers in parentheses the corresponding amino acid numbers in SEQ ID NO:5, and the notation GGG indicates the incorporation at that point of a three glycine helix-breaking linker.

Figure 8 shows a schematic diagram of the IG6 fusion protein (SEQ ID NO:6). The numbers following the backslashes in the legend indicate the position of the peptide component of the native human protein from which its sequence was derived, while the aa numbers in parentheses the corresponding amino acid numbers in SEQ ID NO:6, and the notation GGG indicates the incorporation at that point of a three glycine helix-breaking linker. As indicated in the legend, IG6 comprises, in addition to the indicated portions of human insulin and human GAD 65 (hGAD 65), a C-terminal portion of human IA-2 (hIA2) spanning amino acids 771-979 of the native human protein (amino acids 176-387 of SEQ ID NO:6), with a three glycine helix-breaking linker incorporated at the N-terminus of this portion of IA-2.

Figure 9 shows a schematic diagram of the IG7 fusion protein (SEQ ID NO:7). The numbers following the backslashes in the legend indicate the position of the peptide component of the native human protein from which its sequence was derived, while

the aa numbers in parentheses the corresponding amino acid numbers in SEQ ID NO:7, and the notation GGG indicates the incorporation at that point of a three glycine helix-breaking linker. As indicated in the legend, IG7 comprises, in addition 5 to the indicated portions of human insulin and human GAD 65 (hGAD 65), a C-terminal portion of human IA-2 (hIA2) spanning amino acids 771-979 of the native human protein (amino acids 228-439 of SEQ ID NO:7), with a three glycine helix-breaking linker incorporated at the N-terminus of this portion of IA-2.

10 **SUMMARY OF THE INVENTION** In view of the foregoing, the objects of this invention include the provision of novel chimeric fusion proteins that act as single molecular entities that 1) facilitate diagnosis and prognostic evaluation of individuals suspected of predisposition for the development of IDDM, as well as those 15 suffering from IDDM and/or Stiff-Man syndrome, and 2) to provide enhanced beneficial effects when administered to animals (including human patients) suffering from or at risk of developing autoimmune (Type 1) diabetes. To these ends the invention provides chimeric fusion proteins comprising epitopes 20 of both GAD (glutamate decarboxylase) and insulin. Preferably the GAD is GAD 65 and the GAD and insulin are human GAD and insulin.

In accordance with the invention, the combination of GAD 65 and insulin peptides in a single fusion protein provides a more 25 convenient diagnostic reagent for the detection and prognostic evaluation of diabetes or stiff man syndrome. Discussion of Stiff-Man syndrome may be found, for example in US patent No. 5,691,448, which is incorporated herein by reference.

In accordance with the invention, (and as set forth in the 30 examples, below) the combination of GAD 65 and insulin chains and/or peptides in a single chimeric fusion protein further provides a compound which can be administered so as to furnish more effective immunomodulatory therapeutic treatment than the combination of the same peptides and/or insulin chains as 35 discrete individual peptide moieties and insulin chains. More

specifically, preferred chimeric fusion proteins of the invention, when tested in an assay in a mouse model of IDDM, provide a greater reduction in the frequency of onset of diabetes than a control mixture containing equimolar amounts of 5 each of the various discrete individual peptide moieties and insulin chains comprised by the chimeric fusion protein, each of said individual peptide moieties and insulin chains not being covalently bound to any other of said individual peptide moieties and insulin chains in said mixture, wherein the assay 10 is carried out by the repeated parenteral administration of a number of measured doses, each dose being of a predetermined molar quantity of said chimeric fusion protein in a pharmaceutically effective carrier or of said control mixture in the pharmaceutically effective carrier, the administration being 15 at intervals of not less than twelve hours and not more than 72 hours between each of the doses.

As used herein, the phrase "the same peptides and insulin chains as discrete individual peptide moieties," used in comparison to a particular chimeric fusion protein of the 20 invention, indicates a combination of isolated peptides and insulin chains that are not covalently linked together (e.g., by peptide bonds), wherein linking (via peptide bonds) the peptides and insulin chains together in the appropriate order (e.g., the same relative position in the amino terminal to carboxyl 25 terminal sequence as found in full length GAD 65 and full length insulin chains) would produce the particular chimeric fusion protein of the invention.

While not wishing to be bound by any particular theory of operation, it is believed that complex *in vivo* antigen 30 processing and presentation effects are responsible for the unexpected synergistic effects resulting from combining GAD 65 and insulin peptides and/or polypeptides into a single chimeric fusion protein.

The chimeric fusion proteins of the invention each combine in 35 a single molecular entity the key (immunodominant) autoantigenic

epitopes of both insulin and GAD 65. In so doing, they provide single component diagnostic and therapeutic compounds. The chimeric fusion proteins of the invention provide enhanced beneficial effects after administration to animals (including 5 human patients) when compared to the administration of combinations of the individual peptides representing the same immunodominant epitopes as are comprised within the chimeric fusion proteins.

The preferred chimeric fusion proteins of the invention 10 comprise insulin chain B (e.g., amino acids 1-31 of human insulin) and preferably further comprise insulin chain C (the "C fragment", e.g., amino acids 32-38 of human insulin). Amino acid sequences of insulin chains are known. See, for example, US 15 patent No. 4,431,740, which is incorporated herein by reference for the description of insulin chains and the content of the insulin sequences therein. See also US patent No. 5,008,241, which is incorporated herein for its descriptions and sequences of insulin analogues, which analogues may be substituted for naturally occurring insulin chains in the chimeric fusion 20 proteins of the present invention.

The chimeric fusion proteins of the invention further comprise at least one GAD peptide (i.e., polypeptide polymers of at least ten contiguous amino acids having a sequence identical to a contiguous sequence of at least ten amino acids found in GAD) 25 that is covalently linked (preferably by peptide bonds) to the insulin chain, chains, analogues or peptides.

In accordance with the invention, the at least one GAD peptide is a GAD 65 peptide (i.e., a GAD peptide wherein the contiguous sequence of at least ten amino acids found in GAD is found in 30 GAD 65). Preferably the GAD 65 peptide is a human GAD 65 peptide. Preferably the GAD 65 peptide is selected from the group consisting of human GAD 65 peptides 115-127 (a peptide corresponding to amino acid residues 39-50 of SEQ ID NO:2), 247-286 (a peptide corresponding to amino acid residues 51-90 of SEQ 35 ID NO:2), and 473-519 (a peptide corresponding to amino acid

residues 92-144 of SEQ ID NO:2). Complete amino acid sequences of GAD 65 polypeptides are known. See, for example, US patent No. 5,691,448, which is incorporated herein by reference, particularly for the content of the sequence listings therein.

5 Results of studies described below suggest that the inclusion of human GAD 65 peptide 520-555 (a peptide with an amino acid sequence corresponding to amino acid residues 139-173 of SEQ ID NO:2) has a deleterious effect upon the immunomodulatory outcome of administration of insulin and GAD proteins or peptides.

10 Accordingly, while within the scope of the invention, chimeric fusion proteins comprising human GAD 65 peptide 520-555 are disfavored. Preferably, the chimeric fusion proteins of the invention do not comprise a peptide sequence corresponding to GAD 65 peptide 520-555. It is also preferred that the chimeric

15 fusion proteins of the invention do not include peptide sequences corresponding to those human GAD 65 peptides (particularly those amino terminal GAD 65 peptides) identified as inhibiting GAD solubility in US patent 5,691,448 (which is incorporated herein by reference, particularly for its teachings

20 in this regard) and do not contain peptide regions of GAD 65 that are associated with the pathogenesis of Stiff-Man syndrome. Thus, in accordance with the teachings of Butler et al., 1993, regarding dominant epitopes of GAD recognized by autoantibodies in Stiff-Man syndrome, the preferred chimeric fusion proteins of

25 the invention do not include peptide regions comprising amino acids 1-95 of GAD 65; additionally, they do not include peptide regions comprising either or both of amino acids 475-484 or 571-585 of GAD 65.

30 Preferably the GAD peptides are arranged adjacently to each other (i.e., without more than about three intervening amino acids between them) in the same order as they are found in GAD 65, and the insulin chains are arranged adjacently to each other in the same order as they are found in preproinsulin. An arrangement where the insulin chains are amino terminal to the

35 GAD peptides is also preferred in certain embodiments of the

invention.

In certain preferred embodiments of the invention, at least one (preferably each) of the cysteine residues in the amino acid sequences of the various antigens and antigenic peptides combined to form the chimeric fusion proteins of the invention is replaced with an uncharged amino acid (i.e., an amino acid that is uncharged at a pH of between 6 and 7) having a molecular weight of less than about 150. In another preferred embodiment, none of such cysteine residues are replaced, i.e., there are no substitutions made for any cysteine residues present in any of the various antigens and antigenic peptides combined to form the chimeric fusion protein. When cysteine residues are replaced, the uncharged amino acid is preferably a standard amino acid.

Preferably the standard amino acid is alanine or serine.

Preferably the replacement of cysteine with another neutral amino acid is an epitope neutral replacement, i.e., it does not result in epitope conversion in any of the known immunodominant epitopes of the chimeric fusion protein, particularly those of GAD or insulin.

Detailed discussions of epitope neutral replacements and epitope conversion can be found in copending US application serial No. 08/431,644, filed May 2, 1995 in the names of Steven H. Nye et al., for example at pages 34-36 of the specification of that application as filed. Also see copending US patent application serial No. 08/482,114, filed June 7, 1995 in the names of John P. Mueller et al. Those of skill in the art will readily comprehend the application of the teachings therein to the chimeric fusion proteins of the present invention. Accordingly, copending US patent applications serial Nos. 08/431,644 and 08/482,114 are incorporated herein by reference to more fully describe the epitope neutral amino acid replacements encompassed within the chimeric fusion proteins of the present invention.

It is a further object to provide immunomodulatory methods for both the prevention and treatment of Type 1 diabetes mellitus

and the amelioration of the autoimmune defects underlying this disease. Accordingly, it is an additional object of the invention to provide for the use of the chimeric fusion proteins of the invention in the manufacture of immunomodulatory 5 medicaments.

To achieve these and other objects, the invention provides methods of treating a patient in need of such treatment, e.g., a patient selected from the group of patients consisting of patients at risk of developing type 1 diabetes and patients 10 suffering from type 1 diabetes, so as to delay the onset or reduce the symptoms of diabetes in the patient and/or to ameliorate the autoimmune destruction of pancreatic beta cells in treated patients. Such treatment is particularly advantageous, and is preferably carried out, during the 15 "honeymoon period" early in disease progression, before all of the patient's beta cells have been destroyed by the disease, or later in disease progression, when a patient is a candidate for transplantation of islet cells or tissues containing such cells.

These methods comprise the administration of at least one 20 polypeptide of the invention to the patient. In one preferred embodiment, such administration is carried out on a therapeutic T cell modulatory schedule, i.e., a schedule designed to induce apoptosis, anergy, or other modulation of the autoimmune activity of T cells reactive with at least one epitope of the at 25 least one polypeptide. Particulars of such therapeutic T cell modulatory schedules are discussed below. Other preferred methods of treatment of the invention include administration of at least one polypeptide of the invention to the patient via oral, intravenous, or, preferably, subcutaneous routes, or via 30 parenteral administration with or preferably without an adjuvant such as Freund's incomplete adjuvant, Freund's complete adjuvant, alum adjuvant, or other immunogenic adjuvants now known or subsequently developed.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

35 Chimeric fusion proteins All polypeptides synthesized in

biological systems are initially made with an N-terminal methionine residue. The extreme N-terminal and C-terminal amino acid residues are not considered essential to the functional use of the polypeptides of the invention, which, although not particularly preferred, may be produced without such residues. For example, the polypeptides may be chemically synthesized without N-terminal methionines. Preferred chimeric proteins of the invention thus include IG1 (comprising amino acid residues starting at about residue 2 and ending at about residue 153 of SEQ ID NO:1), IG2 (comprising amino acid residues starting at about residue 2 and ending at about residue 173 of SEQ ID NO:2), IG3 (comprising amino acid residues starting at about residue 2 and ending at about residue 137 of SEQ ID NO:3), IG4 (comprising amino acid residues starting at about residue 2 and ending at about residue 175 of SEQ ID NO:4), IG5 (comprising amino acid residues starting at about residue 2 and ending at about residue 226 of SEQ ID NO:5), IG6 (comprising amino acid residues starting at about residue 2 and ending at about residue 387 of SEQ ID NO:6) and IG7 (comprising amino acid residues starting at about residue 2 and ending at about residue 439 of SEQ ID NO:7). Preferably IG1 comprises amino acid residues 1-154 of SEQ ID NO:1, IG2 comprises amino acid residues 1-174 of SEQ ID NO:2, IG3 comprises amino acid residues 1-138 of SEQ ID NO:3, IG4 comprises amino acid residues 1-175 of SEQ ID NO:4, IG5 comprises amino acid residues 1-226 of SEQ ID NO:5, IG6 comprises amino acid residues 1-387 of SEQ ID NO:6, and IG7 comprises amino acid residues 1-438 of SEQ ID NO:7.

In certain preferred embodiments these chimeric proteins further comprise a histidine tag (i.e., a stretch of at least five and preferably six contiguous histidine residues, which facilitates the purification of the chimeric fusion protein by metal chelation chromatography). Preferably the histidine tag is located at the extreme C-terminus of the chimeric fusion protein. Histidine tags are discussed in greater detail in copending US patent applications serial Nos. 08/431,644 and

08/482,114, which are incorporated herein by reference to more fully describe such histidine tag sequences and their uses.

Accordingly, in certain of these preferred embodiments IG1 comprises amino acid residues 1-160 of SEQ ID NO:1 and has a predicted molecular weight of about 18.8 kDa, IG2 comprises amino acid residues 1-180 of SEQ ID NO:2 and has a predicted molecular weight of about 21.2 kDa, IG3 comprises amino acid residues 1-144 of SEQ ID NO:3 and has a predicted molecular weight of about 17.1 kDa, IG4 comprises amino acid residues 1-181 of SEQ ID NO:4 and has a predicted molecular weight of about 19.8 kDa, IG5 comprises amino acid residues 1-232 of SEQ ID NO:5 and has a predicted molecular weight of about 25.3 kDa, IG6 comprises amino acid residues 1-393 of SEQ ID NO:6 and has a predicted molecular weight of about 43.7 kDa, and IG7 comprises amino acid residues 1-444 of SEQ ID NO:7 and has a predicted molecular weight of about 49.2 kDa.

Secondary Structure Considerations In designing IG4 (SEQ ID NO:4), IG5 (SEQ ID NO:5), and IG6 (SEQ ID NO:6), particular attention was paid to the predicted secondary structures of the polypeptides of the invention. IG4 was initially designed by hypothetically joining peptide epitopes of interest to form a single hypothetical sequence, IG4NHB (SEQ ID NO:8).

Secondary structure prediction of IG4NHB (SEQ ID NO:8) according to Chou and Fasman, 1978; Chou 1990; and Garnier et al., 1978; was performed using LASERGENE sequence analysis software (DNASTAR, Madison WI). This algorithm predicts secondary structure of proteins from their amino acid sequences. Other sequence analysis software may also be used for this purpose, including other commercially available software such as GCG or MACVECTOR.

The entire sequence from amino acid 77 (Phe 77) to amino acid 134 (Thr 134) of IG4NHB (SEQ ID NO:8) was predicted to have helix forming characteristics. The propensity for actual long helix formation diminishes very rapidly for sequences higher than 20 amino acids, with the longest unbroken helices typically

containing no more than 26 amino acids. The 57 amino acid helix-forming sequence from amino acid 77 to 134 of IG4NHB (SEQ ID NO:8) would thus be expected to break at unpredictable, if not random, points so as to form a variety of different 5 structures. Such structures are undesirable in the chimeric fusion proteins of the invention, as they would be likely to be prone to uncontrollable aggregation and would be expected to differ from the native secondary structures of the epitopes in the isolated peptides comprised by the chimeric fusion proteins 10 of the invention and in the native proteins from which the peptides are derived (e.g., insulin, GAD 65, or IA-2), which native secondary structures are preferred for the epitopes contained within the chimeric fusion proteins of the invention. Therefore, in certain preferred embodiments of the invention, 15 helix breakers (see following paragraph) are inserted between the epitopes to 1) block the formation of a very long helix and 2) to predictably separate the epitopes into distinct structural entities with distinct secondary structures.

Helix breakers are amino acids, or groups of sequential amino 20 acids that act to block the propagation of helical secondary structures in nascent polypeptide chains. Gly and Pro are known to be strong helix breakers, Asn and Tyr are weak helix breakers. The insertion of any of these amino acids or combinations thereof in a polypeptide will tend to cause a 25 nascent polypeptide secondary structure helix to terminate at the point of the insertion. To assure helix termination and the separation of the desired epitopes, a helix breaker that is at least two amino acids long (wherein each of the amino acids is the same or different from the other and is selected from the 30 group consisting of Gly, Pro, Asn, and Tyr) is preferred, more preferably, such a helix breaker is at least three amino acids long. Most preferably, the helix breaker is exactly three amino acids long. Highly preferred helix breakers are Pro-Pro-Pro (SEQ ID NO:9) and Gly-Gly-Gly (SEQ ID NO:10), with the latter 35 being the most preferred of these.

Dosage In accordance with the present invention, when used as therapeutic agents, the chimeric proteins of the invention are administered to patients in need of such treatment in amounts ranging from about 6.9 pM/kg/patient to about 8.6 μ M/kg/patient.

5 Preferably the amounts range from about 34.5 pM/kg/patient to about 5.2 μ M/kg/patient. More preferably the amounts range from about 170 pM/kg/patient to about 3.5 μ M/kg/patient. Most preferably the amounts range from about 0.5 μ M/kg/patient to about 3.5 μ M/kg/patient.

10 In certain of its aspects, the present invention also provides for the repeated administration of doses containing lower amounts of the chimeric fusion proteins of the invention to a patient in need of such treatment. Although less preferred, doses containing amounts of below about 6.9 pM/kg/patient, and 15 as low as about 1 pM/kg/patient may be used in the practice of the present invention.

20 Preferably the chimeric proteins are administered without the concomitant administration of an adjuvant, however, when used to perform T cell assays (e.g., in transgenic mice such as described in Wong et al. 1998), initial administration to experimental animals is preferably made with adjuvant.

Administration on Therapeutic T Cell Modulatory Schedules In accordance with the invention, a therapeutic T cell modulatory schedule involves administration of doses containing the 25 chimeric proteins of the invention, preferably in a pharmaceutically effective carrier, repeatedly to the patient, at least two times at an interval of at least six, and preferably at least twelve hours, with an interval of not more than seven days, preferably not more than 72 hours, more 30 preferably not more than 48 hours, and most preferably not more than 24 hours between doses.

35 In accordance with the present invention, the chimeric fusion proteins of the invention are preferably administered parenterally without the concomitant administration of an adjuvant. Administration by a parenteral route will typically

be via injection such as intravascular injection (e.g., intravenous infusion), subcutaneous injection, or intramuscular injection. Other non-oral routes of administration, e.g., mucosal, inhalation, transdermal ultrasound, and the like, may 5 be used if desired and practicable for the particular polypeptide to be administered.

Although less preferred, the chimeric fusion proteins of the invention may also be administered orally, however dosages for oral administration will typically be one to two orders of 10 magnitude higher than those discussed above under the sub-heading "Dosage."

Formulations suitable for injection and other routes of administration are well known in the art and may be found, for example, in Remington's Pharmaceutical Sciences, Mack Publishing 15 Company, Philadelphia, PA, 17th ed. (1985). Preferred formulations for parenteral administration of the proteins of the invention are those described for insulin in the USP 23/NF 18 (1995).

Parenteral formulations must be sterile and non-pyrogenic, and 20 generally will include a pharmaceutically effective carrier, such as saline, buffered (e.g., phosphate buffered) saline, Hank's solution, Ringer's solution, dextrose/saline, glucose solutions, and the like. Formulations may also contain pharmaceutically acceptable auxiliary substances as required, 25 such as, tonicity adjusting agents, wetting agents, bactericidal agents, preservatives, stabilizers, and the like.

Further discussions of dosage and administration of polypeptides using therapeutic T cell modulatory schedules may be found in copending US patent applications serial Nos. 30 08/431,644 and 08/482,114 (discussed above) and copending US patent application serial No. 08/565,769, filed December 1, 1995 in the name of Yi Wang, each of which is hereby incorporated herein by reference in its entirety to more fully describe the state of the art to which the present invention pertains.

35 Without intending to limit it in any manner, the present

invention will be more fully described by the following examples.

Experimental Methods Non-obese diabetic (NOD) mice are a strain of mice that are prone to the development of diabetes, 5 and represent an accepted model system for the study of diabetes mellitus. These mice, designated NOD/MrkTacfBR, were purchased from Taconic Farms (Germantown, NY). NOD SCID mice, designated NOD/SCID, are available from the Jackson Laboratories, Bar Harbor, ME. The incidence of diabetes by 200 days of age in 10 these mice is 80% in females and 50% in males. At 110 days of age, fewer than 15% of the male NOD mice became diabetic.

CYTOXAN induction experiments: CYTOXAN (Cyclophosphamide) treatment can increase the incidence and accelerate the onset of diabetes in non-diabetic NOD mice. Randomly selected, non- 15 diabetic male NOD mice, which were 100 to 110 days of age, were injected (ip) with cyclophosphamide (250mg/kg) on day 0.

All the mice were subjected to urine glucose measurement 2-3 times per week for a period of 21 days after cyclophosphamide injection. The onset of diabetes was recorded as the first 20 point at which two consecutive days of positive urine glucose results were obtained. Blood glucose was also measured to confirm the urine glucose results. (ExacTech, MediSense Inc., Cambridge, MA) In all the mice tested with positive urine glucose, blood glucose levels were greater than 150mg/dl. At 25 day 21, these mice were sacrificed and examined histologically.

Experiments in the NOD/SCID Adoptive Transfer Model: Spleen mononuclear cells were harvested from diabetic NOD mice of recent disease onset (diabetic not more than 3 weeks) and about 35 x 10⁶ of these spleen cells in 0.2 ml of PBS were injected 30 intravenously into 6-8 week old NOD/SCID mice. Onset of diabetes was monitored biweekly by urine glucose testing and confirmed by blood glucose testing on day 28 relative to the time of spleen cell transfer. At day 28, these mice were sacrificed and examined histologically.

35 Reagents: CYTOXAN (cyclophosphamide, Mead Johnson oncology

products) was dissolved in distilled water (25mg/ml). Oxidized bovine insulin Chain B was purchased from Sigma (catalog no. I-6383). Both insulin chain B and the BSA control protein (Miles Inc., #81-001) were dissolved in PBS/1M HCL, pH2, before 5 dialysis against PBS, pH7.2, sterile filtration, and storage of frozen aliquots.

EXAMPLES

Genes for expression of chimeric proteins of the invention

10 **IG1.** A synthetic chimeric gene encoding chimeric protein IG1 (SEQ ID NO:1) was constructed in two rounds of overlapping PCR (Ho et al., 1989). Each gene subdomain was synthesized in a standard PCR 100 μ l reaction using 10 pmole of each of the appropriate oligonucleotide primers, as described below. The 5' 15 gene segment was amplified using the overlapping primers: prIG1 (SEQ ID NO:11), and prIG2 (SEQ ID NO:12). The 3' gene segment was amplified using the overlapping primers prIG3 (SEQ ID NO:13) and prIG4 (SEQ ID NO:14). The prIG1 oligo-nucleotide (SEQ ID NO:11) was designed to allow creation of a unique *Nde*I 20 restriction site at the 5' end. The prIG4 primer (SEQ ID NO:14) included a unique *Bam*HI site, stop codon (TAA) and 18 nucleotides that encoded a histidine tag sequence for purification of the recombinant chimeric protein by metal affinity chromatography. The two subdomains were combined using 25 flanking oligonucleotides prIG5 (SEQ ID NO:15) and prIG6 (SEQ ID NO:16) in a second PCR reaction to yield a 492 bp gene product. The PCR product was cloned into expression plasmid vector pCR2.1 as described by the supplier (Invitrogen, San Diego, CA). Kanamycin-resistant DH10B transformants were selected and the 30 correct clones and orientations determined by restriction and sequence analysis. Restriction fragments from two clones (#6 and #18) were combined to remove undesired mutations. Following nucleotide sequence analysis, an independent plasmid pCR2.1-IG1 was digested with *Nde*I and *Bam*HI and the 492 bp fragment 35 inserted into compatible sites of the MP4 expression plasmid

pET22b-MP4 (Elliott et al., 1996), yielding plasmid pIG1. The insert from pCR2.1-IG1 was also subcloned into plasmid vector pBLUSCRIPT[®]SK+ (STRATAGENE CLONING SYSTEMS, La Jolla, CA) to yield plasmid pSK+IG1. The synthetic IG1 gene (SEQ ID NO:17) 5 encodes a chimeric fusion protein with a predicted mass of about 18.8 kDa.

IG2. A synthetic chimeric gene encoding chimeric protein IG2 (SEQ ID NO:2) was constructed by PCR amplification of an internal IG1 gene fragment using pIG1 as a template along with 10 the sense primer prIG7 (5'-AGATCTGATG AACATTCTGC TGCAGTATGT TGTTAAAAGC TTTCGATAACA TGTATGCCAT GATG-3' - SEQ ID NO:18; *Bgl*II site underlined) in combination with the anti-sense oligonucleotide primer prIG8 (5'-TGTACAGATA TTCCGCCAGT TCCAGACATT TTTTCAGAGA AAAATGGCTA TGTTTCAGAGG TAAAGGCAAT CAGACGCG- 15 3' - SEQ ID NO:19; *Bsr*G1 site underlined). The 197 bp *Bgl*II-*Bsr*G1 PCR fragment was subcloned into pCR2.1. Sequence analysis revealed a C>G substitution at position 183 in the coding strand of the 197 bp *Bgl*II-*Bsr*G1 PCR fragment for all subclones analyzed, and the plasmid was named pCR2.1-IG7/8C183G. 20 Subsequent analysis revealed an error in the original prIG8 primer sequence (SEQ ID NO:19). A repair primer, prIG12 (SEQ ID NO:20), was synthesized to correct the C>G substitution in pCR2.1-IG7/8C183G. The internal 197 bp *Bgl*II-*Bsr*G1 DNA segment was corrected by PCR using pCR2.1-IG7/8C183G as a template along 25 with primers prIG7 (SEQ ID NO:18) and prIG12 (SEQ ID NO:20). The PCR fragments were subcloned into pCR2.1, their sequence was determined using standard dideoxy sequencing to confirm that the desired sequence had been obtained, and a single clone designated pCR2.1-IG7/12 was isolated and amplified.

30 The 137 bp *Bgl*II-*Bsr*G1 restriction fragment in pSK+IG1 was exchanged with the 197 bp *Bgl*II-*Bsr*G1 fragment from pCR2.1-IG7/12 to create pSK+/IG7/12. The 552 bp *Nde*I-*Bam*HI fragment from pSK+/IG7/12 was subcloned into the compatible sites of pIG1 to create plasmid pIG2. The synthetic IG2 gene (SEQ ID NO:21)

encodes a chimeric fusion protein with a predicted mass of about 21.2 kDa.

IG3. A synthetic chimeric gene encoding chimeric protein IG3 (SEQ ID NO:3) was constructed by removing a 552 bp *NdeI-BamHI* 5 restriction fragment from plasmid pET22b-IG2 and substituting an *NdeI-BamHI* digested 444 base pair PCR product therefor. This 444 base pair PCR product was made using primers prIG5 (SEQ ID NO:15) and prIG13 (SEQ ID NO:22) with the synthetic IG2 gene as a template. The synthetic IG3 gene (SEQ ID NO:23) encodes a 10 chimeric fusion protein with a predicted mass of about 17.1 kDa.

IG4. A gene sequence encoding chimeric protein IG4 (SEQ ID NO:4) is set forth below as SEQ ID NO:24, and encodes a chimeric fusion protein with a predicted mass of about 19.8 kDa.

IG5. A synthetic chimeric gene encoding chimeric protein IG5 (SEQ ID NO:5) was constructed via ligation of PCR products using primers prIG14 (SEQ ID NO:25), prIG15 (SEQ ID NO:26), prIG16 (SEQ ID NO:27), prIG17 (SEQ ID NO:28), prIG18 (SEQ ID NO:29), prIG19 (SEQ ID NO:30), prIG20 (SEQ ID NO:31), prIG21 (SEQ ID NO:32), prIG22 (SEQ ID NO:33), and prIG23 (SEQ ID NO:34). The 20 synthetic IG5 gene (SEQ ID NO:35) encodes a chimeric fusion protein with a predicted mass of about 25.3 kDa.

IG6. A gene sequence encoding chimeric protein IG6 (SEQ ID NO:6) is set forth below as SEQ ID NO:36, and encodes a chimeric fusion protein with a predicted mass of about 43.7 kDa.

IG7. A gene sequence encoding chimeric protein IG7 (SEQ ID NO:7) is set forth below as SEQ ID NO:37, and encodes a chimeric fusion protein with a predicted mass of about 49.2 kDa.

Expression and purification of recombinant IG fusion proteins.

For each IG fusion protein expression plasmid construction that 30 was bacterially expressed, electrocompetent *E. coli* strain BL21(DE3) was transformed with the expression plasmid and ampicillin-resistant colonies were selected for liquid culture. The lDE3 lysogen in strain BL21(DE3) contains the gene for T7 polymerase behind the *E. coli* lacUV5 promoter for efficient 35 expression of target genes under control of the strong

bacteriophage T7 transcriptional and translation signals (Studier et al., 1990).

The recombinant chimeric fusion protein was purified from solubilized whole cell pellets by immobilized metal affinity chromatography and analyzed by SDS-PAGE/Coomassie blue staining. Four liters cultures were grown to OD₆₀₀ of 0.8 in Terrific Broth (TB) medium (Sambrook et al., 1992). Protein expression was induced for 5 hours with 1mM isopropylthiogalactoside (IPTG). Induced cells were harvested by centrifugation and frozen overnight at -20°C. Cell pellets were thawed at room temperature and homogenized in 10 ml/g of Buffer A (6 M guanidine-HCl/10% glycerol/20 mM Tris-Cl pH 7.8/500 mM NaCl/200 mg sodium sulfite/280 mg sodium tetrathionate) using a TEKMAR homogenizer (The Tekmar Co., Cincinnati, OH). Cells were frozen at -70°C for 1 hour and thawed at room temperature to promote cell lysis. The cell suspension was gently mixed for 30 min at room temperature using a magnetic stirrer. The soluble fraction containing IG protein was collected as the supernatant following centrifugation of the cell lysate at 10,000xg for 30 min at 4°C in a Beckman JA-10 rotor. The supernatant was loaded on a Ni-NTA (QIAGEN Inc., Chadsworth, CA) column previously equilibrated in Buffer A at a flow rate of 8 ml/min. The column was washed to baseline absorbance using Buffer A. The column was further washed with Buffer B (6 M urea/10% glycerol/20 mM Tris-Cl/500 mM NaCl pH 7.8) and contaminating *E. coli* proteins were removed with Buffer C (6 M urea/10% glycerol/20 mM Tris-Cl/500 mM NaCl pH 5.0). IG protein was eluted with Buffer D (6 M urea/10% glycerol/20 mM Tris-Cl/500 mM NaCl pH 4.0). All fractions were collected in batch and analyzed on a 4-20% SDS-polyacrylamide gradient gel in the presence of reductant. The IG containing fractions (Buffer D wash) were concentrated 10-fold using an AMICON STIRCELL using a PM10 membrane. The sample was dialyzed against two changes of MILLI-Q water at 4°C. The IG preparations were filter sterilized and the concentration determined

spectrophotometrically using a conversion factor of 1.06 mg/ml/OD₂₈₀. Five micrograms were analyzed under reducing and nonreducing conditions by SDS-PAGE so as to obtain an initial indication of purity and integrity of the protein preparations.

5 Chimeric fusion protein treatment -- CYTOXAN model: Groups of randomly selected NOD mice were injected intravenously twice daily with either BSA as a control, or GAD peptides, insulin chain B (ICB) or various combinations of GAD peptides and/or insulin chain B at the doses indicated in the figures on days 1, 10 3, and 5 following CYTOXAN treatment (day 0). Animals that received injections of BSA (controls) manifested a greater than 80% incidence of diabetes by 21 days following CYTOXAN induction (Fig. 2). In contrast, animals treated with either ICB or either 15 of GAD 65 250-273 or 520-555 peptides, experienced reductions to less than 50% incidence of diabetes. The therapeutic effects of treatment with combinations of ICB and the two GAD peptides were then examined (Fig. 3). Reduction in diabetes incidence to 25% or less was achieved by the combination of GAD 250-273 and ICB at doses of 100 ug or 250 ug per injection.

20 Surprisingly, the addition of GAD peptide 520-555 (amino acid residues 139-173 of SEQ ID NO:2) appeared to inhibit the therapeutic efficacy of the ICB with GAD 65 250-273 combination. Evaluation in the CYTOXAN model of the IG1 and IG2 chimeric fusion proteins of the invention, showed that treatment with 25 either of these polypeptides mediated a dose-dependent reduction in the incidence of diabetes compared to the BSA treated control animals (Fig. 4). In this experiment, 300 ug doses were more effective than 100 ug doses, and IG2 reduced the incidence of diabetes to a greater degree than IG1. Treatment with 300 ug 30 doses of IG2 reduced disease incidence to less than 12%, compared to greater than 80% disease incidence in the BSA treated control animals.

Chimeric fusion protein treatment -- adoptive transfer model:

Diabetogenic splenic mononuclear cells were harvested from 35 newly diabetic NOD mice (onset less than 3 weeks previous). To

initiate the destruction of islet beta cells and the development of diabetes, 8-12 week old NOD/SCID mice were injected intravenously with 35×10^6 diabetogenic spleen cells. The incidence and onset of diabetes were monitored biweekly by 5 urine glucose testing and confirmed by blood glucose testing at the end of the experiment. The average onset time of diabetes after disease induction was approximately 25 days. IV treatment with IG2, IG3, or islet beta cell antigens was initiated on day 3. Animals were treated with 300ugs of antigen 10 twice daily every other day for a period of six days (from day 3 to day 9, where the time of spleen cell transfer was day 0).

The results of these experiments are set forth in Figure 5. They surprisingly demonstrate that only the IG2 chimeric fusion protein prevented the onset of disease in the NOD/SCID 15 recipients. In contrast, in this model only a slight delay in disease onset was observed in recipients of IG1, insulin chain B (ICB), or the combination of ICB and GAD peptide 250-273. These profound differences in the effects of treatment with IG2 as compared to the other treatment regimens was unexpected. 20 Without wishing to be bound by any particular theory of operation, it is believed that this unexpected finding is a result of the *in vivo* processing of IG2 into unique antigenic peptides that are particularly effective at eliciting a state of immune tolerance protective against autoimmune diabetes, 25 even in the demanding conditions resulting from challenge with heterogeneous T cell populations derived from the spleens of fully diabetic NOD mice.

Although preferred and other embodiments of the invention have been described herein, further embodiments may be perceived by 30 those skilled in the art without departing from the scope of the invention as defined by the following claims.

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TABLE 1

Table-1: dose dependency of cyclophosphamide induced diabetes in non-diabetic male NOD recipients

CYTOXAN	# Diabetic / Total	%	Mean onset time
200mg/kg	2 / 7	28.6%	12
250mg/kg	5 / 7	71.4%	11
300mg/kg	5 / 7	71.4%	12.6